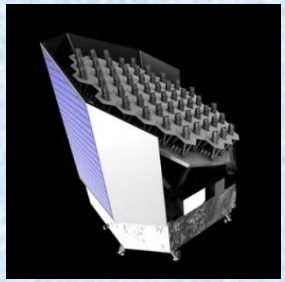


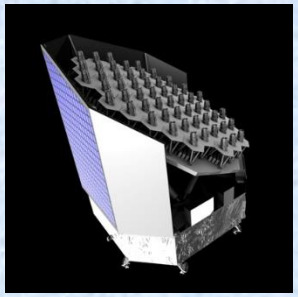
The TESS Input Catalog and Lessons For PLATO

Prof Joshua Pepper

Lehigh University

Credit to Keivan Stassun, Martin Paegert, David Latham, Nathan De Lee, Guillermo Torres, Ryan Oelkers, and many others

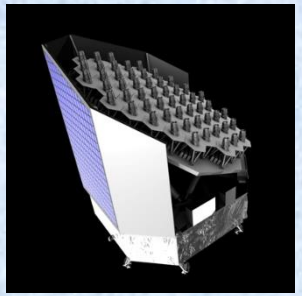
TESS and PLATO



Sources:

- Rauer, et al. 2014 “The PLATO 2.0 Mission”, ExA, 38, 249
- Rauer, et al. 2016 “The PLATO Mission”, AN, 337, 961
- https://sci.esa.int/web/plato/home
- Nascimbeni, et al. 2016 “An all-sky catalogue of solar-type dwarfs for exoplanetary transit surveys”, MNRAS, 463, 4210
- Montalto, et al. 2021 “The all-sky PLATO input catalogue”, A&A, 653, 98

TESS and PLATO



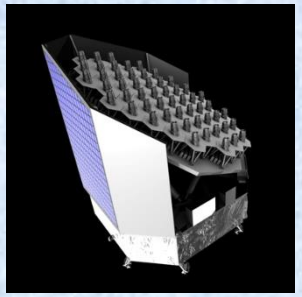
TESS

- All-sky survey
- Transit goals
  - Bright host stars and atmospheric studies
  - Planet detections
  - Small planets (< 4 R_E)
- No expectations for asteroseismology of hosts
- 20.25” pixels
- FFIs
- Open follow-up program
- Strong support for GO program

PLATO

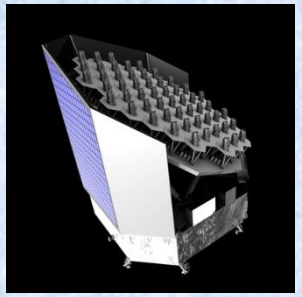
- Targeted fields
- Transit goals
  - Bright host stars and atmospheric studies
  - High precision system parameters
  - Primary focus on solar-type stars
- Asteroseismology of (all?) the transit hosts
- 15” pixels
- No FFIs?
- Mission-supported follow-up program
- Strong support for GO program

Goals of an Input Catalog



- Select stars for targeted observations (postage-stamp / imagette downloads)
- Define the local star field in the neighborhood of the target star
- Select fields to observe
- Provide observational and physical information about the target stars
  - For candidate evaluation and vetting
  - For planetary characterization

Target Star Selection

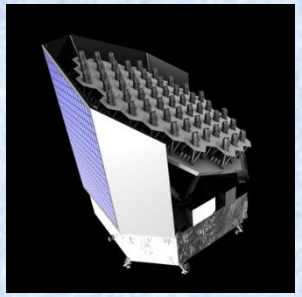


- Star properties relevant to selection
  - Broadband magnitudes
  - Extinction/reddening
  - Parallax/distance
  - Mass, radius, surface gravity
  - Variability
    - Photometric: Eclipses, ellipsoidal variation, rotation/spots, flares
    - Spectroscopic: SB status

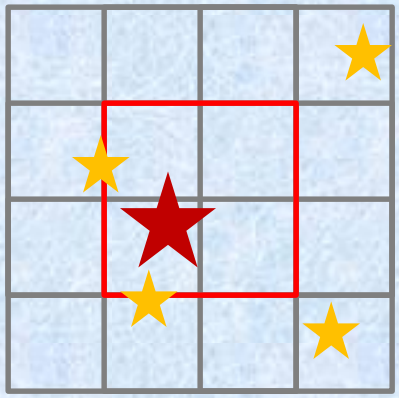
10^9

$\sim 270{,}000$

Target Star Field



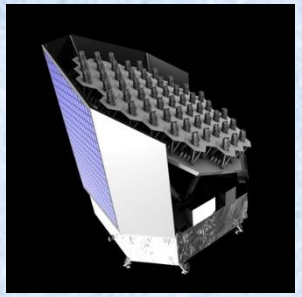
- What other stars are nearby?
  - Define the pixel aperture and flux contamination (what fraction of the photons that you are capturing come from the target star?)
  - Source contamination
    - Where is the signal coming from?



What magnitude limit do you require for both of these goals?

- Flux contamination: 2-3 mags
- Source contamination: ~7-9 mag

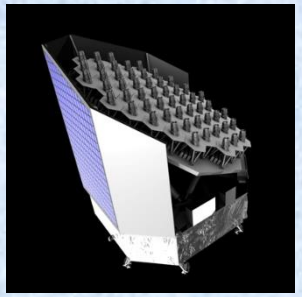
Target Star Field



- What other stars are nearby?
  - Define the pixel aperture and flux contamination (what fraction of the photons that you are capturing come from the target star)
  - Source contamination
    - Where is the signal coming from?
- Multiple regimes
  - Seeing-limited / common resolution-limited: about 1”

See Ziegler, et al. 2018 “Measuring the Recoverability of Close Binaries in Gaia DR2 with the Robo-AO Kepler Survey”, AJ, 156, 259

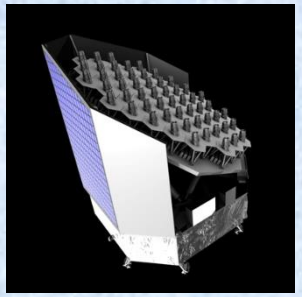
Target Star Field



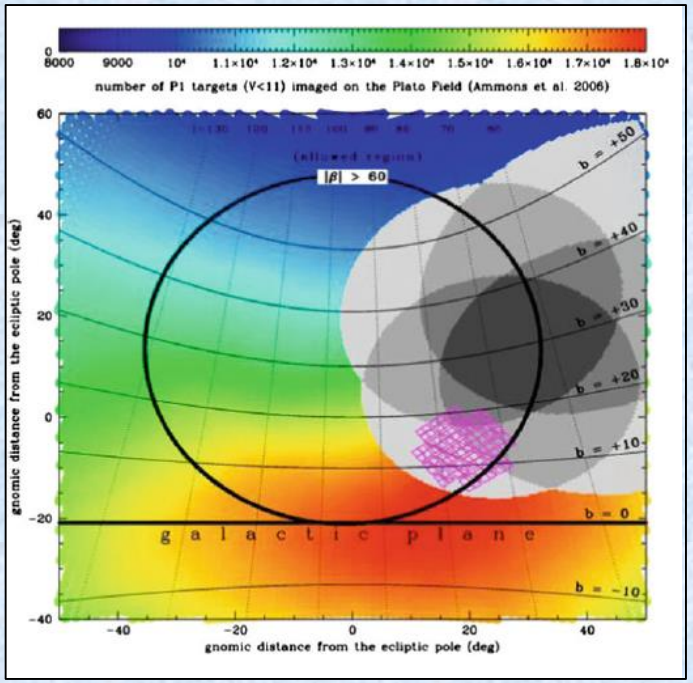
- What other stars are nearby?
  - Define the pixel aperture and flux contamination (what fraction of the photons that you are capturing come from the target star)
  - Source contamination
    - Where is the signal coming from?
- Multiple regimes
  - Seeing-limited / common resolution-limited: about 1”
  - High angular resolution

Not accessible for $O(10^6)$ stars, but maybe $O(10^3)$, such as the P2 sample?

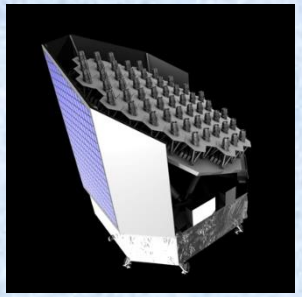
Field Selection



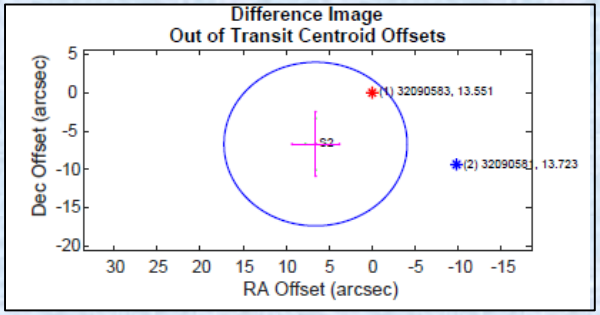
- Typical background contamination
  - Flux contamination
  - Source contamination
- Number of good target stars per square degree
- Other considerations:
  - Follow-up access



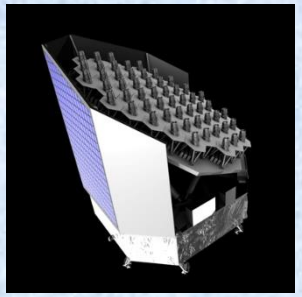
Vetting Candidates



- Is the signal consistent with being planetary?
  - Reliability of $\log g$ and R_*
- Can we eliminate standard false positive scenarios?
  - Reliability of nearby star field identification, including magnitudes in observed bandpass
  - Necessary for interpretation of centroid analysis



Developing the TIC



- Earliest active TESS Working Group: starting January 2012

WG Chairs: Keivan Stassun and Joshua Pepper
Dozens of active members (esp. Martin Paegert, Nathan De Lee, Guillermo Torres, Ryan Oelkers)

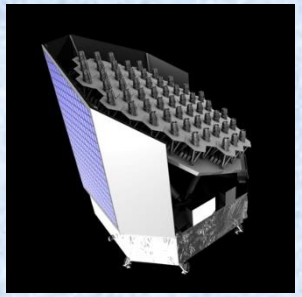
- Task officially completed with delivery of TIC-8 in April 2019

Stassun, et al. 2018 “The TESS Input Catalog and Candidate Target List”, AJ, 156, 102

Stassun, et al. 2019, “The Revised TESS Input Catalog and Candidate Target List”, AJ, 158, 138

Fausnaugh, et al., 2021, “The TESS Mission Target Selection Procedure”, PASP, 133, 5002

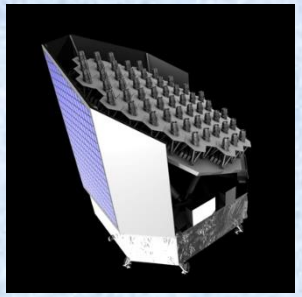
Challenges for the TIC



- Gaia DR2 not available before launch
  - Huge effort to differentiate giants, subgiants, and dwarfs via available parallaxes and reduced proper motions
- Extra effort to identify M dwarfs by Phil Muirhead and Courtney Dressing

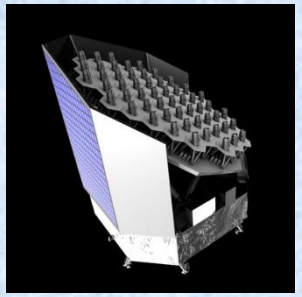
Muirhead et al., 2018 “A Catalog of Cool Dwarf Targets for the Transiting Exoplanet Survey Satellite”, AJ, 155, 180

Challenges for the TIC



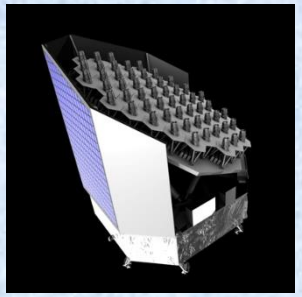
- Gaia DR2 not available before launch
  - Huge effort to differentiate giants, subgiants, and dwarfs via available parallaxes and reduced proper motions
- Extra effort to identify M dwarfs
- Switch from 2MASS as base catalog to DR2
  - Effort to maintain completeness with 2MASS led to significant numbers of phantom objects
- The galactic plane is a mess
- Handling phantoms (splits, joins, artifacts)

Advantages for the PIC



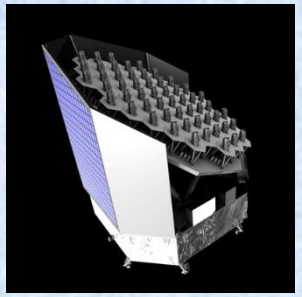
- Gaia EDR3 + later versions
- Other catalogs
  - Spectroscopic surveys (e.g. APOGEE, LAMOST)
  - Specialized catalogs (e.g. RECONS)
- Asteroseismology
- TESS photometry

Lessons from the TIC for the PIC



- Completeness vs. reliability
- Stellar multiplicity
- Selective inclusion of available data
- Updating objects and preserving backwards compatibility with TIC IDs
- Multiple avenues of public access
- Long-term support
- Variability, TESS photometry (and RUWE)

Lessons from the TIC for the PIC



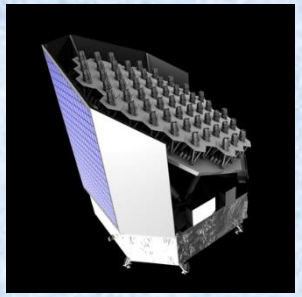
Completeness vs. Reliability

- Target stars
- Background stars

Abundance of target stars:
Maximize reliability

Accounting for background stars:
Balanced approach

Lessons from the TIC for the PIC



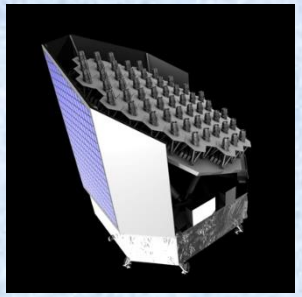
Stellar multiplicity

- Effects on planet detection
  - Individual detections
  - Mission detection statistics

Ciardi, et al., 2015 “Understanding the Effects of Stellar Multiplicity on the Derived Planet Radii from Transit Surveys: Implications for Kepler, K2, and TESS”, ApJ, 805, 16

Bouma, Masuda, & Winn 2018 “Biases in Planet Occurrence Caused by Unresolved Binaries in Transit Surveys”, AJ, 155, 244

Lessons from the TIC for the PIC

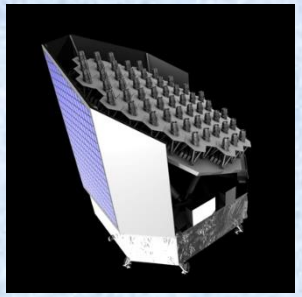


Which additional catalog data to include?

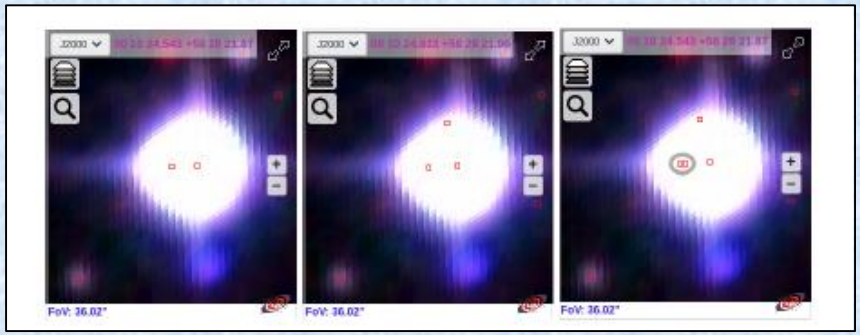
- Elemental abundances
- Chromospheric activity indicators
- Stellar population (disk membership, cluster/association membership)
- Etc.

Relevance for individual and statistical evaluation of detections (and nondetections!)

Lessons from the TIC for the PIC

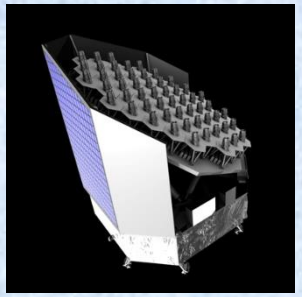


- Updating objects and preserving backwards compatibility with TIC IDs
- Handling phantoms
  - Artifacts
  - Splits
  - Joins
- Future PIC versions



Paegert, et al. 2021 “TESS Input Catalog versions 8.1 and 8.2: Phantoms in the 8.0 Catalog and How to Handle Them” arXiv:2108.04778

Lessons from the TIC for the PIC



Multiple avenues for public access

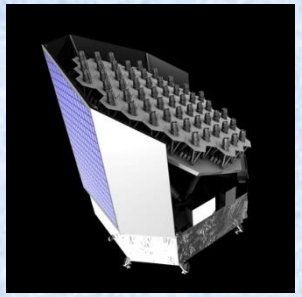
Object searches

Parameter searches

Cone searches

Bulk downloads?

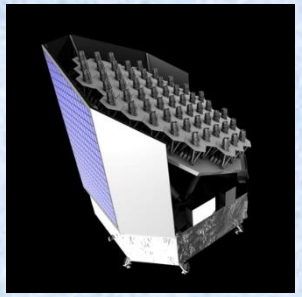
Lessons from the TIC for the PIC



Long-term support

- Updating the PIC
  - Future Gaia DRs, other sky surveys? (versions 2, 3, etc.)
- Maintenance of the PIC
  - Fixing individual or systematic errors (versions x.2, x.3, etc.)
  - Feedback from users, including vetting teams, follow-up teams, and others
  - Documentation

Lessons from the TIC for the PIC



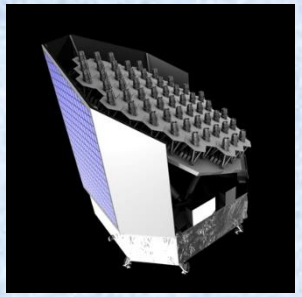
Variability and TESS photometry and Gaia RUWE

"TESS is not a statistical mission!"
- David Latham

Maximize number of planet detections?
vs
Enable most robust statistical analysis?
vs
Limit other scientific investigations?

P1/P2
vs
P5?

Final Thoughts



- Plan for success! → Long-term PIC support
- Early and close coordination with archive management
- Any opportunity to obtain FFIs should be pursued
- Think carefully about skewing target selection to maximize planet detections
- How will you use the TESS data and binarity information?
- For the love of all that is holy and good in the world, maintain backwards PIC ID compatibility!